

THESIS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

Integrated structural and construction engineering –
A study of project team performance in Swedish
bridge design

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ABSTRACT

The Swedish Transport Administration (STA) ambitiously strives to increase the level of productivity and innovation within its operations while meeting and surpassing national sustainability objectives. In this effort, the STA has concluded that climate gas emissions from construction, operation, and maintenance of the infrastructure must be reduced for Sweden to maintain its position as a pioneer and to reach both national and global climate goals. Emissions from road, rail, and other civil works is mainly related to the production of construction materials, such as construction steel, concrete and reinforcement in bridges, retaining walls, and other structures. For bridges, normally designed for a long service-life, the environmental impact of all stages after realization is greatly dependent on and constrained by decisions made during design and construction of the structure. To succeed in realizing effectiveness in bridge construction project is only possible by close cooperation between all project participants, i.e. client, consultant(s), and contractor(s).

The construction industry is often described as complex, multidisciplinary, and project-focused but with no clear boundaries of who actually owns processes and, consequently, the development of them. The overall purpose of this research is, therefore, to contribute to framing a systematic and holistic design approach fostering many kinds of project-settings and pre-requisites. This research aims to further understand how to introduce construction knowledge in the early design stages through utilizing an approach with integrated projects teams. The thesis is based on several studies exploring how integration is related to the bridge construction process and the key features are for such integration. Further, this thesis explores the prevailing interprofessional dialogue in the Swedish bridge construction process and how this may both support and hinder knowledge and experience transfer in the interprofessional interface.

Given the complexity in construction today, all participants involved, individually, will lack some pieces of the puzzle, but that collectively, they can gather their knowledge and resources to achieve success for all parties involved. When integration is seen from this perspective, the following key features crystallize; skills to collaborate and communicate; interdependency between the parties; importance for the structural engineer to receive feedback from, and to have a dialogue with, the contractors; teams to be provided with the right people.

The contribution of this thesis is that it provides further knowledge to develop and improve the contemporary approach in the design and construction of bridges.

Keywords: integration in construction, integrated design, collaboration in construction, inter-disciplinary, interprofessional dialogue, integrated project teams, structural design, sustainability, performance, buildability, constructability, bridges, concrete structures, pre-construction indicators, conceptual design, project competence, project culture

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Preface

This thesis is the result of the work carried out from March 2014 until September 2019 at Chalmers University of Technology, Department of Architecture and Civil Engineering, Division of Structural Engineering, Concrete Structures. The work has been a part of an ongoing collaboration between WSP, Swedish Transportation Administration, and Chalmers in order to enhance the prevailing work in design and construction of bridges.

First and foremost, I would like to thank my academic supervisors, Mario Plos and Rasmus Rempling. Thank you for your guidance and tremendous support in my, at times rough and wandering journey towards being a PhD. Magnus Gustafsson, without your unconditional commitment, this would not have been possible. A special thanks also to WSP, and especially my closest colleagues and my, since recent, former manager Roland Olsson for supporting me in this opportunity. Peter Simonsson and Mats Karlsson, Trafikverket for both being very supporting and closely attached to the project during all these years. I would like to thank members of the reference group for your support during the first part of this project, including Per-Ola Svahn, Petra Bosch, Peter Harryson, Pontus Bengtson, Kent Gylltoft, and Henrik Franzén.

Also, thanks to Alexandre Mathern, Peter Nilsson, Stefan Uppenberg, Carlos Gil Berrocal, Ignasi Fernandez, and Christina Claesson-Jonsson for both interesting and challenging discussions and collaborations over the years forcing me to challenge status quo. Finally, thanks to all my present and former colleagues at both WSP and Chalmers!

Sara, Meja, and Lova. Finally there! Let's see what comes next!

Nödinge, September 2019

Daniel Ekström

LIST OF PUBLICATIONS

This thesis is based on the work presented in the following papers:

- A. Ekström, D., Rempling, R., Plos, M. (2019): Study of approaches to meet the ends in bridge design and construction – It's time to walk the talk. Submitted to *Structural Engineering International*
- B. Ekström, D., Rempling, R., & Plos, M. (2019). Integrated project team performance in early design stages – performance indicators influencing effectiveness in bridge design. Published in *Architectural Engineering and Design Management*, 15(4), pp. 249–266.
- C. Ekström, D., Rempling, R. (2019): Closing the knowing-doing gap in the feedback loop – A study of experience and knowledge transfer in bridge construction projects. Submitted to *Architectural Engineering and Design Management*
- D. Ekström, D., Rempling, R., Claeson-Jonsson, C. (2019): Predicting project performance using pre-construction performance indicators – a case study evaluation. Published in *Proceedings of 2019 IABSE Congress New York City, The evolving Metropolis*, September 4-6 2019.

ADDITIONAL PUBLICATIONS BY THE AUTHOR

Conference papers:

- 1. Ekström, D., Rempling, R., Plos, M. (2014): Industrial bridge building- An effective bridge construction process through an integrated design and construction process. Published in *Proceedings of the XXII Nordic Concrete Research Symposium*, (0800-6377). Vol. 2014 (2014), 2, p. 79–82.
- 2. Ekström, D., Rempling, R., Plos, M. (2015): Industrial bridge construction: Need for a more effective bridge construction process. Published in *Proceedings of the Eighth International Structural Engineering and Construction Conference, Sydney, Australia*, November 23-28, 2015 p. 1115-1120.
- 3. Ekström, D., Rempling, R., Plos, M. (2019): Integrated project team in early design stages – Key variables influencing cost effectiveness in bridge building. Published in *Proceedings 19th IABSE Congress Stockholm, Challenges in Design and Construction of an Innovative and Sustainable Built Environment*, September 21-23 2016 p.
- 4. Ekström, D., Al-Ayish, N., Rempling, R., Simonsson, P., Plos, M. (2017): Climate impact optimization in concrete bridges – towards sustainable construction. Published in *Proceedings 39th IABSE Symposium Vancouver, Engineering the future*, September 19-23 2017.

Popular science

1. Ekström, D., Rempling, R., Plos, M. et. al. (2014): Samarbetsprojekt för effektivare brobyggande. Published in Bygg & Teknik (0281-658X). Vol. 2014 (2014), 7, p. 58–61.
2. Al-Ayish, N., Uppenberg, S., Ekström, D. (2018): Reducerat koldioxidutsläpp från betongbroar genom dagens tillgängliga teknik. Published in Husbyggaren 2018, 2108 (1), 15–18.

1 Introduction

As a primary goal, the Swedish Transport Administration, (STA), has concluded that climate gas emissions from construction, operation and maintenance of the infrastructure must be reduced if Sweden should keep the position as a pioneer and to reach both national and global climate goals. This is done by setting long-term requirements for resource efficiency as well as reduction of greenhouse gas emissions from construction, operation and maintenance of infrastructure. To a great extent, the emissions from road and rail and other civil works (WSP, 2013) is related to the production of materials used in construction, such as construction steel, concrete and reinforcement in bridges, retaining walls and other structures. This should be a clear signal to the construction industry to work harder to lower its climate impact and be resource efficient.

In view of national sustainability objectives, the STA, ambitiously strives to increase the level of productivity and innovation within its operations. The construction industry is often described as complex, multidisciplinary, and project-focused and with no clear boundaries of who actually owns processes and, consequently the development of them. The industry is also considered as a one-of-a-kind nature; hence, the industry tends to focus on the uniqueness of projects rather than similarities.

Over the years, since multiple references have highlighted the inefficiencies in the construction process (Latham, 1994; Egan, 1998; Bygghandlingsverket, 2002; Statskontoret, 2010; SOU, 2012), it has become evident that the design and construction process needs to be understood in another way in order to facilitate all the elements essential in delivering a project, such as buildability, sustainability, productivity etc. In construction, sources to inefficiencies are mainly identified to occur in the interaction between different trades. This is also in general related to the self-interest of different parties which makes them put themselves first (Forbes and Ahmed, 2011). The integration of different trades in the construction industry has been the focus of research for several years in order to generate a more effective process (Oakland and Marosszeky, 2006; Larsson *et al.*, 2014). Integration has also been a prioritised area by the STA for much the same reason – meeting the efficiency challenge. Utilisation of industrial thinking is one of the contemplated approaches to meet that challenge. Industrial thinking is an important prerequisite for long-term and continuous productivity and innovation development in the construction industry and should permeate the entire construction process from the early stages to management stages (Harryson, 2008; Simonsson, 2011; Larsson *et al.*, 2014).

However, both practice and research has shown that the transition towards industrial thinking in construction is laborious and requires major changes, not only for suppliers to STA, but also for STA itself as a client organisation (Harryson, 2008; Simonsson, 2008; Larsson *et al.*, 2014). One step in that change, is the transition from being project-oriented to process-oriented in construction. Yet, adopting to a process-orientation means a stronger focus on similarities than differences and also increases the demands on upstream activities. In contrast to the infrastructure sector, the housing sector in Sweden has enjoyed better success in this transition. One part of that success is due to a clear customer positioning, allowing for example housing companies to gain control over a much larger part of the supply chain including all activities from sale to delivery of the finished house (Lessing, 2006; Lidellöw *et al.*, 2015). However, operations within a customer organisation like STA ranges from small, individual bridges in rural areas to major infrastructure changes in heavily urbanised and trafficked areas. This variation

also turns STA into a complicated client requiring construction services and products ranging from a clean sheet design to off-the-shelf products (e.g. Jensen & Larsson, 2013). Consequently, this variation creates a market complicated to niche and this complexity is one of the reasons why industrial initiatives within bridge construction are rare.

Thus, to be successful within the infrastructure sector, in contrast to housing, even greater emphasis needs to put at the process rather than the product. A greater focus on processes, by necessity places greater focus on teams and the collaboration within and between teams.

According to Egan, (1998), both process-orientation and team integration are necessary changes for the construction industry to become more successful. However, simply bringing people together does not necessarily ensure they will function effectively as a team. Effective teamwork does not occur automatically. It may be challenged by various issues, such as lack of organization, misunderstandings, poor communications, and inadequate participation from team members. Therefore, it is crucial for construction project teams to find a solution to help their team members to integrate and work together effectively.

1.1 Research gap

There is plenty of research concerning integration in construction and bridging the gap between design and construction (Latham, 1994; Egan, 1998; Winch, 2003; Simonsson, 2011). Still, there is a predominant amount of research conducted in relation to construction methods and how to create an effective construction process. Less attention is directed towards the structural design process and how this enables construction activities to be more effective. Further, to use integrated project teams and extended collaboration is usually one of the outspoken ingredients for creating that change in the construction industry. Unfortunately, research results have often been rather ambiguous as to what integration in such cases entails, and how integration ultimately affects the individual during the design process. Suggesting increased teamwork and multidisciplinary/ interprofessional collaboration is likely to point out the right direction for this industry to go, but what does it mean to work integrally and together, and in a close relationship between contractors, designers, and clients? What are the opportunities and tools available to use at lower organizational levels to make things happen? In the end, it is finally what is done on the "floor" which often determines the benefit of the change.

1.2 Scope

The research primarily departs from the prevailing situation in Sweden, although the work is internationally relevant. For this research the design and construction process were identified to consist of three major stages, pre-construction, construction and post-construction. The focus of this research is from a structural design perspective in the pre-construction stage and how activities undertaken during this stage best facilitates both the construction and post-construction stages. Moreover, the project further delineated its focus on short- and medium-span road bridges.

1.3 Purpose and research questions

The overall purpose of this research is to contribute to the ambitious task of framing a systematic and holistic design approach which can foster many kinds of project-settings and pre-requisites. Through the adoption of a design approach more oriented towards construction procedures, it is more likely to establish the progress that the construction industry needs. Supporting that purpose, this research explores and aims to further understand how to introduce construction knowledge in the early design stages while utilizing an approach of integrated projects teams.

In an overall perspective and by the conducted research, there is an ambition to contribute to the development from the contemporary approach in design and construction of bridges. The research is intended to contribute to a push towards a change in both attitudes and ways of working in the bridge construction process. That includes a change towards a more enhanced use of industrialized thinking in the design and construction of bridges and an improved productivity and value added in investments.

The following research questions support fulfilling the above stated purpose:

RQ1: What is integration, and what are its key features in relation to the bridge construction process?

The first research question aims to define integration in the bridge construction process and what are the key features for integration

RQ2: What defines the interprofessional dialogue bridge construction process and how can it support the introduction of construction knowledge during early design?

The second research question aims to define the interprofessional dialogue in the bridge construction process and how this can support knowledge and experience transfer in the interprofessional interface.

1.4 Limitations

As previously highlighted, the pre-construction stages are vital for how to undertake construction and in many cases for the entire service life for a structure. The focus on integration is therefore placed on the pre-construction and early design stages. A comprehensive and exploratory approach has been adopted to this project, leaving the author with much freedom when choosing the direction. Despite that, a natural limitation is the adapted perspective from a structural engineer and how structural engineering and design issues are both effected and how this effect the integration of design and construction process.

Some limitations identified for the project are the following:

Even though, a large amount of international literature is studied, the perspective of the study is primarily focused at the current and future situation in Sweden. This is the market the research first and foremost aims to influence. Still, we claim this work to be applicable within an international perspective as well since the major part of the developed countries faces the same issues or problems, even though in different cultural contexts.

Despite the effort to strengthen knowledge concerning the integrated project team, no sub-study was conducted at a construction site, or towards a specific ongoing

construction project. There is also a reason for that. Although it is of greatest importance for researchers to have both knowledge and understanding concerning construction in general as well as construction work procedures, this research sought for a shift towards earlier stages, i.e. greater degree of upstream involvement from downstream actors.

Further, when doing research, it is easy to get caught in the “bubble” and focusing so hard at the specific task that there is a risk of missing what is happening in “the real world”. For me, being an active bridge designer, it is easy to see and follow the developments from "my" angle, but I am still quite limited to insight when it comes to the developments within contractor companies. Nevertheless, focus for this research has been to study how the working methods during design can be improved, and of course I have had a clear advantage from following my colleagues and the development at close range during all the years that this research has progressed.

2 Method

In this chapter the research is briefly described, and the methods used for carrying out the research are discussed. The discussion starts with a justification for the choice of overall research approach, followed by the choice of more specific methods.

2.1 Research design and process

Understanding how integration is understood, perceived, and how it might work better has involved a long explorative journey. There was an early understanding that progress required a much broader perspective than normally adopted within our research group. Addressing the issue with a new set of eyes, or at least with a set of eyes normally trained to see other things, required that we as researchers stepped back and raise your eyes.

It would have been perfect if this chapter described a neat research plan and how this plan was followed while ticking the boxes as the research progressed. Still, there is no point in pretending, nor trying to present some sort post-fact rationalisation. That perfect plan did not exist, our research design could not be compared with having a blueprint in your hand as described by Bryman, (2006) rather a clean sheet. The adopted approach is more similar to active design. We dug a hole and saw what we found and made a decision based on that. This approach made the journey quite arduous, with some extra holes being dug along the road. Yet, we have been determined not to follow the already trodden pathway since it has led to the current incomplete understanding of integration in the construction industry.

We have deliberately along the journey tried to keep what we study at such a generalized level as possible. By that we mean that most research done in the area study the behaviours under specific circumstances, instead we tried to lift the respondents outside the project-specific context and instead let them give us their general/overall view/opinion. This approach is still in line with a case study approach, yet the context is moved to the individual. This approach is not without problems or difficulties and challenges the researcher to interpret the responses from the context from where it originated.

The performed work for this research followed four subsequent steps presented in Figure 1 in order to establish a theoretical foundation for integration in construction as well as to establish an understanding of how to view and approach integration at the level of the individual engineer. The four steps are further explained in Section 2.2.

As a start we needed to gain a broad and general understanding of both the field of research and industry practice. The first milestone was to establish a clear focus and to understand in what direction the project should be directed and therefore aimed at a comprehensive literature review. At this stage, to use a qualitative approach is then a good start, since qualitative research is not based on a unified theoretical and methodological concept. Instead, a subjective viewpoints are a good first starting point (Flick, 2014). So, the purpose for a literature review as method, was primarily to generate a distinct understanding of the field and narrowing the area to be studied.

Adopting to an explorative approach towards existing literature and interpreting it based on many years of experience from the bridge sector allowed us to obtain a deeper knowledge of underlying root causes for the prevailing problems the construction

industry is experiencing. Further, the review created a picture of common approaches claimed to enhance and/or improve the construction industry.

From the results of the analysis in Paper A, three subsequent studies were conducted and presented in Paper B, C and D. The progression of the research is schematically displayed in Figure 1.

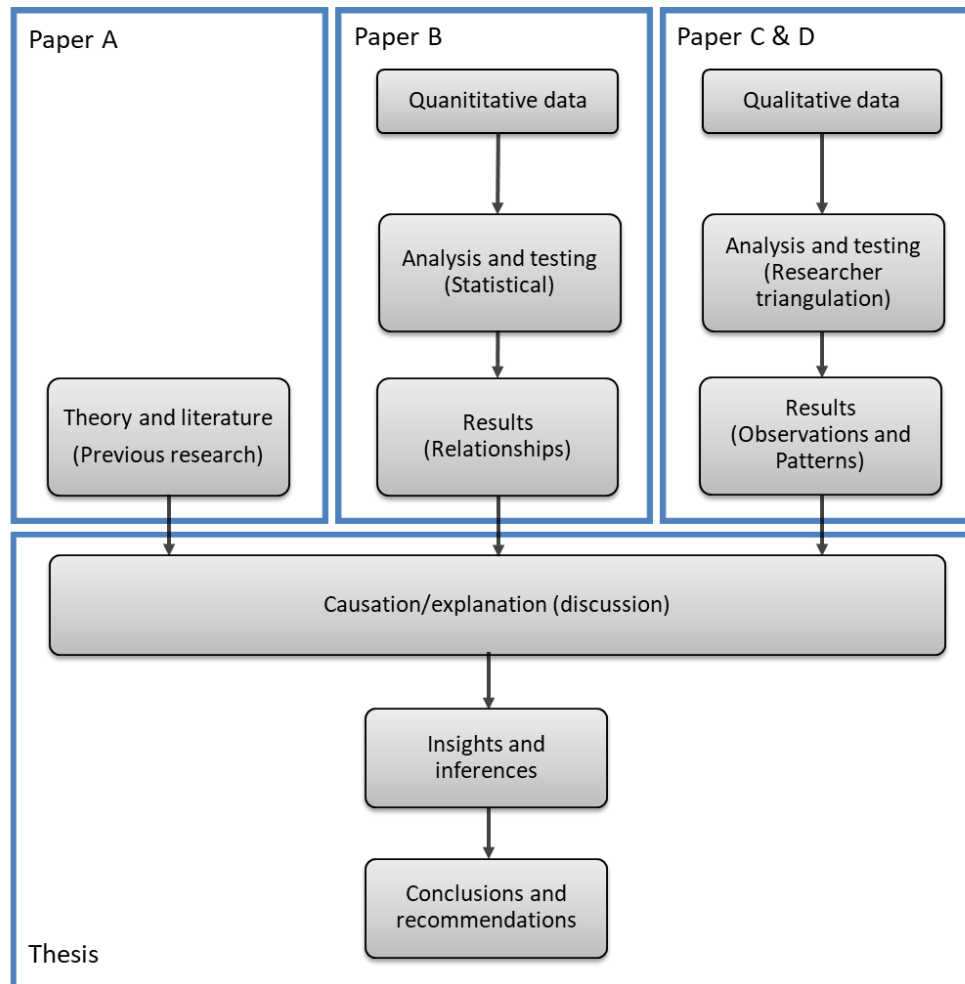


Figure 1: Model to use to inspire our research design. Modified from (Fellows & Liu, 2015)

Qualitative and quantitative research approach

For the project, a long term research study was used (Bryman, 2006; Bryman & Bell, 2011). First and foremost, the primary data gathered was of qualitative nature but for one of the four reported studies quantitative data was gathered. Thus, this thesis draws on data collected with several different methods. Jick, (1983) states that “*Qualitative and quantitative methods should be viewed as complementary rather than rival camps*”, in (Flick, 2014). So, both a qualitative and quantitative approach was used for this thesis. However, the main principal approach has been gathering qualitative data. To use mixed approaches is supported in the contemporary literature on research methods e.g. (Bryman & Bell, 2011; Flick, 2014), where it is stated that research may include both qualitative and quantitative approaches in different phases of the process. The suggestion is to use qualitative research for developing hypotheses, which afterwards

will be tested with quantitative approaches and vice versa (see e.g. Bryman & Bell, 2011).

Available approaches in research are normally related into two main approaches, qualitative and quantitative, but also the use of a mixed approach of the two formers are more frequently addressed as a third separate approach (Bryman & Bell, 2011). There are some basic differences separating the approaches, which at the simplest level can be explained by saying that a quantitative approach aims to transform information into numbers, diagrams and tables, in contrast to a qualitative approach where the researcher's own interpretations of the information are in focus but cannot be transformed into numbers and instead concerns words, behaviours etc. Yet, it is important that the choice between different approaches are based upon the purpose of the study and the most suitable approach for achieving the specific goal of the research. For example, Yin, (2014) lists five major research methods to gather data in research (*experiments, surveys, archival analyses, histories and case studies*) and the choice of method depends on three conditions: *the type of research questions posed, the extent of control the researcher has over actual behavioural events, and the degree of focus on contemporary events*.

How to conduct data analysis is the part of qualitative research that most distinctively differentiates from quantitative research approaches. Quantitative research mainly relies on statistical methods, in contrast to qualitative research which focuses on the exploration of beliefs, understanding, opinions and views of the phenomenon (group or individual e.g.) under investigation (Fellows and Liu, 2015). There exists a wide variety of data collecting methods and qualitative research often contains unstructured text-based data. The most commonly methods for gathering data in qualitative research denoted in literature are; observations, interviews, and documents (see e.g. Bryman & Bell, 2011; Flick, 2014; Fellows and Liu, 2015), and the type of research ultimately determines which is most suitable. Although, and most importantly, qualitative research relies on the interaction with the field and the individuals being studied (Flick, 2014) and instead of primarily being a technical exercise as in quantitative research, qualitative research adopts a more dynamic, intuitive and creative process of inductive reasoning, thinking, and theorising (Basil, 2003).

The process of analysing qualitative data predominantly involves coding or categorising the data. Basically, it involves making sense of huge amounts of data by reducing the volume of raw information, followed by identifying significant patterns, drawing meaning from data and subsequently constructing a logical chain of evidence (Patton, 2002; Graneheim & Lundman, 2004). Coding or categorising the data is the most important stage in the qualitative data analysis process. Coding and data analysis are not synonymous, though coding is a crucial aspect of the qualitative data analysis process. Coding merely involves subdividing the huge amount of raw information or data, and subsequently assigning them into categories (Graneheim and Lundman, 2004; Maguire & Delahunt, 2017; Nowell *et al.*, 2017). In simple terms, codes are tags or labels for allocating identified themes or topics from the data compiled in the study.

2.2 Research approaches

Despite the choice of approaches for any research project, they are all associated with both strengths and weaknesses. Thus, it is important for the researcher to gain knowledge of the associated strengths and weaknesses for the selected approach for collecting data and how it further affects the analysis of the data (Fellows & Liu, 2015). Furthermore, the researchers' pre-knowledge and the researchers' view upon the

subject affects the progression of research process. This effect is especially critical for qualitative research where the researcher's subjectivity, and of those being studied, become a part of the research process (see e.g. Bryman & Bell, 2011; Flick, 2014).

The following sections describe different research approaches and data gathering methods used for this research and are presented separately for each appended paper. In accordance with literature, the research questions governed the choice of method. Thus, each method is described in relation to the literature, as well as in terms of how research was conducted and what measures were taken to increase trustworthiness of the results. Further, a reasoning of how and in what way the specific results could be generalised.

Literature review, Paper A

The objective of the comprehensive literature review was to identify the common foundation for the suggested improvements of design and construction. Due to the variety and diversity in the identified approaches, there is a need for clarification in the field to be able to adopt changes. From the identified concepts, it is possible to provide a framework for the progression to the use of industrialized processes in construction. Different approaches used to generate productivity improvements in the construction industry are presented, evaluated and compared. The reasoning in the paper sheds light to the common features of the approaches and that they necessarily do not exclude each other.

The literature review conducted for paper A aimed to identify some of the distinctive theories/concepts described in literature to transform construction. Over the years, many clients and construction organizations have adopted new approaches at a strategical level, but what this means and how this affects the everyday activities at an operational level is still unclear in the industry. After these key theories/concepts had been identified and investigated, they were further categorized and compared regarding their similarities and dissimilarities. Both Swedish and international construction research was studied, yet with a perspective from the challenges and implications for the Swedish context.

To increase the utilization of industrial processes in construction and to adopt an integrated design approach has, in some way, been a predetermined direction for the Swedish bridge construction industry as a result of both academic and governmental reports (Bygghälsögruppen, 2002; SOU, 2012; Larsson *et al.*, 2014). Although this roadmap, or transition pathway, was already “established” by many years of research in the field, where or how to walk was still somewhat vague. The roadmap was still drawn on a relatively high strategic level. Since this research intended to focus on the interface between two key disciplines in bridge construction, structural engineering and construction engineering, reasoning for the qualitative approach in paper A was to broaden the perspective and to establish further direction for the research.

The conducted review was therefore of an exploratory character and explored a large amount of existing research literature and the observation of previous studies describing the multifaceted problem to generate a more effective bridge construction process. The literature was chosen based on the preconception that integration of disciplines and a collaborative working environment enhances project success. For the review, a multi-step procedure was employed beginning with an initial review of interesting views and aspects in relation to the development of the construction process followed by a more in-depth exploratory review, see Figure 2. Based on the initial review and the level at

which results were presented in the literature, we observed that all the efforts made to generate necessary change within the construction industry were very similar yet claimed to be different.

The continued and a more focused exploration of the literature was conducted at three levels. The first step established what the core principles are within each concept and where they originate from. The second step describes the approach towards integration and the distribution of responsibilities to create such an integration. The third and final step defines similarities and dissimilarities between the different concepts and links pre-construction and construction activities.

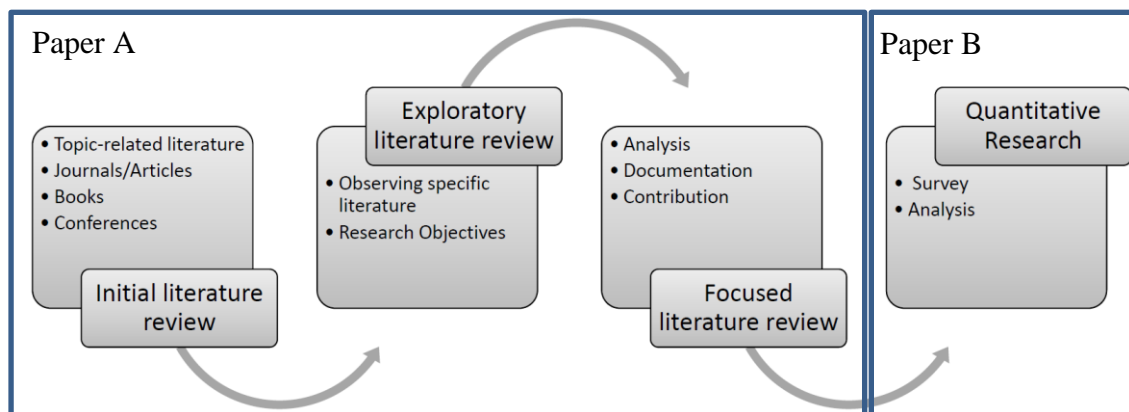


Figure 2: The subsequent stages of the conducted research (for paper A and B).

The research in paper A, aimed to establish a comprehensive, although far from complete, review of literature concerning proposed approaches and concepts to develop the construction process. The review included important research and development of project delivery, design teams, and the industrialisation of construction. Further, the literature review also established the foundation for the questionnaire study performed in paper B.

Literature reviews for the other studies are presented in each of the appended papers.

Survey, Paper B

For the survey for paper B, data was collected through a questionnaire. The study originated from the basic point to understand the different construction project participants and their perception of project performance. The objective for this second step was to identify a framework and areas of improvement in terms of generating effectiveness within Swedish bridge design teams. Using the framework supported an assessment of a part of construction sector and in order to generate an overall view of how collaboration and communication are used in the prevailing way of work and thus, giving an indication of where to address the main efforts of improvements.

The area of project team performance is complex and multi-facetted and what areas in it to approach needed to be further specified. The reason for choosing a questionnaire was based on the possibility to create such a priority between different aspects within project team performance. For the study, a framework was developed by combining previously established theoretical references (Josephson & Björkman, 2011; Rempling, Fall & Lundgren, 2015), and to pre-define nine different indicators, see Figure 3, to support that prioritizing.

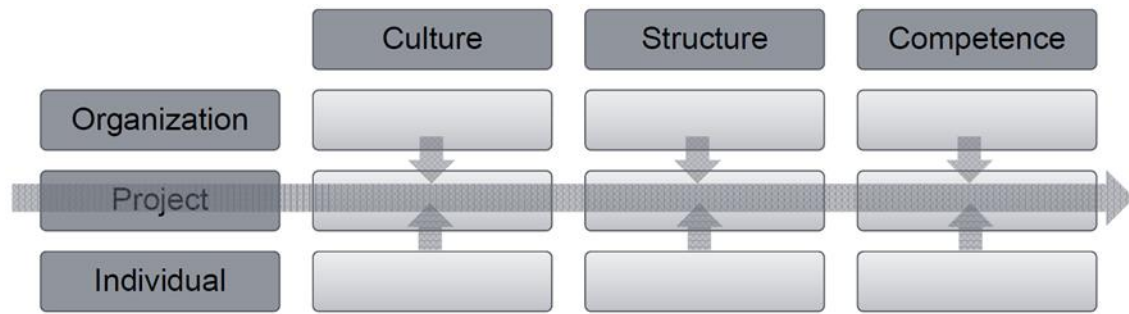


Figure 3: Survey evaluation matrix for Paper B

The questions used for the questionnaire were developed informed by a self-assessment questionnaire, e.g. (Wheelan, 2016). Such questionnaires are proposed by several team literature authors (Mickan & Rodger, 2000; Wheelan, 2009; Salas *et al.*, 2017) to provide aid to identify how to develop a group of individuals into high performance teams (HPT). In this study, the questions support the examination of how the collaboration between different disciplines works during the planning, design, and development of construction documents for new bridges in Sweden. The questions were sorted and organised into the three different levels of organisational hierarchy: organisation, project, and individual. Furthermore, the questions were also arranged according to the driving forces for customer value: culture, structure, and competence, see Figure 3.

The survey questions were originally formulated by the author; thereafter they were discussed, modified and rephrased within the reference group for the Ph.D project.

Data collection

The respondents were presented with 45 statements and were asked to answer to what extent the statement agreed with their way of working (*performance*) and to what extent this was important for the degree of project success (*importance*). Each statement was measured on a 5-point Likert scale, see e.g. (Bryman & Cramer, 2011), where 5 represents a high degree of conformity and 1 no conformity. By adopting a Likert scale to the responses it is possible to assign a numerical value to something that is a subjective opinion (Bryman & Cramer, 2011). In addition, for each statement the respondent was given the opportunity to add additional text to support their answers.

The respondents were given a short-written introduction to the aim and scope of the survey. The introduction was given to support coherence amongst the respondents regarding a target case, which they were asked to relate their responses to.

The survey was administrated to clients, contractors, and structural engineering consultants in the Swedish bridge construction industry, and distributed electronically. A total of 134 persons completed the survey. Besides the major client, STA, the respondents represented some of the largest construction and consultancy firms in Sweden. Of the 134 survey respondents there were 20 representing the client, 52 a contractor, and 62 a consultant.

Importance Performance Analysis

The Importance-Performance Analysis (IPA) model was initially presented and introduced by Martilla and James (1977) with the intention of providing a simple and graphical tool for the development of business marketing strategies (Abalo *et al.*, 2007). Combining the importance and performance measures allows for the IPA to be presented as a grid divided into four quadrants that offer a visual understanding of

overall user satisfaction (Bruyere *et al.*, 2002). The four quadrants are normally interpreted as “keep up the good work”, “concentrate here”, “low priority” and “possible overkill”. Here, the importance measure is represented on the vertical axis, and the performance measure at the horizontal axis of a two-dimensional graph.

IPA is a popular and widely spread method used in many different fields, both in academia and practice. The health care and tourism industries are the most frequent users, but the method is well documented also in the field of construction management (Albaloushi & Skitmore, 2008; Eom & Paek, 2009; Eom *et al.*, 2009; Chang *et al.*, 2017). Similar approaches also exist, for example in (Jergeas & Put, 2001) to evaluate potential benefit and the effectiveness of applying constructability principles in the Canadian construction industry. Also, (Al Mousli & El-Sayegh, 2016) assess the design-construction interface problems in the United Arab Emirates construction industry.

In IPA literature there is limited empirical evidence to support which of the derived and direct importance approaches performs best in assessing the relative importance in IPA application. The value of using IPA is to evaluate relative importance and performance scores (Martilla & James, 1977). To use an absolute evaluation significantly limits the discriminatory and predictive power of stated importance measures (Azzopardi & Nash, 2013). The analysis used here follows the procedure proposed for the traditional Importance-Performance Analysis (IPA) together with the Gap 1 analysis, described by (Feng *et al.*, 2014).

Survey analysis

Five statements are presented within every area leaving the range of score in each block between 5-25, and the total score for each organisational level in the range of 15-75, see Figure 4. In the analysis, it is possible to generate a mean value for each indicator leaving the final total score for each organisational level on a range of 5-15. By using this kind of multiple-item scale it is more likely that the generated responses give a broader view of the concept measured. This also makes it possible to draw finer distinctions between the different indicators and also minimize the error from questions being misunderstood (Bryman & Cramer, 2011).

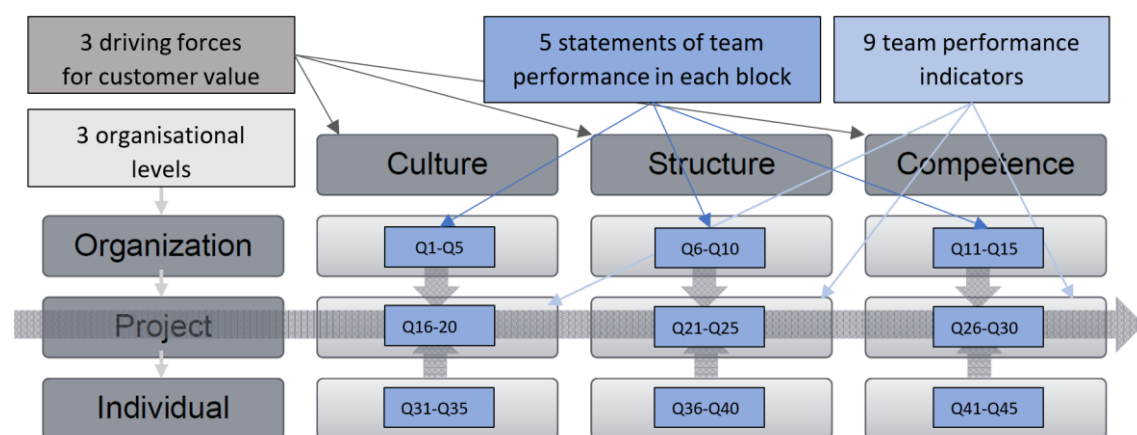


Figure 4: Survey evaluation matrix, explanation.

Research has established that from the characteristics of a team it is possible to determine a team's development level, and further a relationship between a team's level of development and its performance. The concept of team development has over the years been well documented and multiple authors have established theories in the field

of team formation and its performance (Tuckman, 1965; MacMillan, 2001; Wheelan, 2009). Teams functioning at the higher stages of development are found to be more productive (Wheelan, 2009, 2016). Scoring high on performance in the evaluation would indicate a highly mature and effective group, a so called high performance team (Wheelan, 2016). Wheelan, (2009, 2014) divides her integrated model of group development into four stages described as, (1) dependency and inclusion, (2) counter-dependency and fight, (3) trust and structure, and (4) work, a stage of intense productivity and effectiveness. In addition to determining performance, the respondents were asked to evaluate the importance of each statement regarding project success.

Interviews, Paper C

For paper C, qualitative interview methodology (Kvale & Brinkmann, 2014) was applied in order to explore how industry professionals, within the Swedish bridge construction industry, perceive knowledge and experience feedback as well as their abilities to collaborate and to share information and knowledge. The study explores how these actions are perceived both within the professional's own organisation as well as in relation to other interorganisational team members. The study was conducted with representatives from some of the largest construction and consultancy companies in the Nordic EU-countries. The interviewees were geographically spread over Sweden, but the most of them were conducted in the Gothenburg or Stockholm areas.

All interviews have been based on a semi-structured interview guide that constitutes a checklist of issues to discuss. This means that the interview was not constrained by any specific script or time limit. Although the interview guide acted as a structure for the interaction, the discussion was allowed to evolve as appropriate for the participant. In total, 17 interviews were conducted with personnel representing a client's organisations (2), contractors (6) as well as structural engineers (9). The interviews were conducted in the form of conversations that lasted between 55 and 105 minutes and all took place at the participants' places of work.

All interviews were recorded and transcribed. Notes were kept during the interview and used as a support to debrief each interview. The interviews are not completely comprehensive, or representative for the Swedish bridge construction industry in general but highlight several issues sufficiently that are generic and therefore not only of interest for the individual case. Anonymity was guaranteed to the participants to encourage as much frankness as possible during the interview.

Selection

The chosen participants were originally identified through a selection of individuals who previously completed a questionnaire survey (Ekström *et al.*, 2019). A purposeful sampling (Bryman & Bell, 2011; Flick, 2014) was made for the study to get as wide and accurate description as possible of the phenomenon to be studied. Selected persons have both different roles in their professions as well as a breadth of experience to ensure a sufficient variation of perspectives on the phenomenon discussed. A common factor amongst the chosen individuals is that they are all individuals expected to have a lot to say about the area to be described.

Determining the size of the sample in a qualitative study is not entirely self-evident, and the starting point is to continue to interview people until no more new comments appear (Kvale & Brinkmann, 2014). Numerically determining the degree of saturation is usually not necessary, nor is the selection aimed at statistical generalisability. Instead,

the number of interviews is considered to be sufficient when data saturation is achieved and verified.

Analysis

Qualitative content analysis is a method to stepwise analyse written or verbal communication while focusing on differences and similarities. There was no predetermined theory being investigated in the interviews, but rather the responses were examined for key points. The interpretation process results in one or several themes. A theme acts as a common thread which runs through each meaning-unit, code and category (Graneheim & Lundman, 2004).

The first step in the analysis is to generate an understanding and overall view over the collected material. Each interview is therefore listened to after it was finished, and then transcribed. All interviews were transcribed by the authors, and the interviews were imported to a qualitative analysis program and broken down into meaning-units in accordance with content analysis (Graneheim & Lundman, 2004; Maguire & Delahunt, 2017; Nowell *et al.*, 2017). These units are then further condensed into shorter sentences and finally concluded into a code describing the content of that meaning-unit. Codes with similar content are grouped into subthemes and further, the subthemes finally are grouped into larger parent themes which constitutes the final observations (Graneheim & Lundman, 2004).

An additional and important step in the process also includes sorting and excluding material outside the themes in the interview guide and that are not relevant for the study. The remaining text constitutes the analysis unit. In this study, main categories were formed by the codes formed by our transcription material. A number of subcategories were also created, which gave rise to subheadings in the study result. The participants were numbered in the transcribed material with numbers 1-17 to distinguish them during processing of the data.

Case study - Document analysis, Paper D

For paper D, a retrospective document analysis (Flick, 2014) was conducted. The reason was to explore the interprofessional dialogue within the structural design team and how industry professionals use their abilities to collaborate and share information and knowledge, both within their own organization and to other interorganizational team members. The case for this study was chosen with the preconception to be a generally considered successful project, including the perspective of the client, contractor, as well as the structural design engineer.

The documents are notes of meetings and have therefore been reviewed and edited in accordance with common meeting documentation procedure. The meeting notes have been documented by the engineering office for the purpose of recording decisions and responsibilities as a project management tool. Consequently, a series of design meetings was arranged parallel to the original plan. Each meeting was documented including information concerning date; place; participants and affiliation; task and associated responsibility. All known protocols concerning the re-design were gathered and stored in a case study database (Flick, 2014). The targeted audience is the project members as well as the mother organizations of the client, contractor, and engineering office.

The analysis approach for the project meeting documentation was made as a qualitative content analysis (Kvale & Brinkmann, 2014). Qualitative content analysis is a method to stepwise analyse written or verbal communication while focusing on differences and similarities. The interpretation process results in one or several themes. A theme acts

as a common thread which runs through each meaning-unit, code and category (Graneheim & Lundman, 2004).

The qualitative data consists of 17 documents. Initial codes were generated deductively based on our prior research, the conceptual framework of integrated design, and our field expertise. Codes were first fit into a pre-existing coding framework of the main theme as meaning units. The coding was then refined through interpreting the meaning units and condensing them into to provide a detailed analysis of aspects of the data. Codes with similar content were subsequently then grouped into sub-themes (Graneheim & Lundman, 2004).

The following step in the process required researcher triangulation (Anney, 2014). The triangulation included separate coding by a group of researchers. First, a group of two researchers performed a preliminary coding of the documents by coding for theoretical and reflective units as well as additional potential codes and themes. Secondly, a third researcher coded the content identified as interesting in the coding structure of the themes. After the research triangulation, a review of the generated codes and themes were done, and the coded material was checked for referential adequacy by returning to the meaning unit. The names of themes were discussed as well as the sub-theme structure. Following this coding methodology (Nowell *et al.*, 2017) we strove for trustworthiness and credibility in approach and interpretation.

2.3 Validity and reliability

During the research process, several methods were used to collect data. The overall validation₂ was obtained using multiple sources of evidence, collected by the multiple data collection techniques, e.g., document analysis, questionnaires, interviews and case studies.

Using questionnaires leaves the researcher with somewhat limited control over the environment, thus leaving the validity of the results dependent on how the respondents understand the questions as well as their honesty. The objectivity of the results from a questionnaire may consequently be questioned. A five-point Likert-scale was chosen for the questionnaire, but a larger spread from using seven-point scale might have provided more information due to the larger response range. A seven-point scale would also probably have yielded a wider span in the collected data. Further, when using questionnaires there is always a possibility that some respondents do not understand the questions properly and instead answer the questions arbitrarily. However, a reference group conducted a pilot to pre- test both for the comprehensibility of the questions as well as the applicability of the actual data collection.

Any interview situation is by nature exposed to the influence of the researcher, as it is impossible for the researcher to be completely objective. To establish validity to the findings, excerpt from the interviews were include in the article. Also, to determine the size of the sample in a qualitative study is not entirely self-evident, and there is a risk that the numbers of interviews are too few to be fully representative.

Purposeful sampling (Bryman & Bell, 2011; Flick, 2014) was chosen for the study to get as wide and accurate description as possible of the phenomenon to be studied. Selected professionals have both different roles in their professions as well as a breadth of experience to ensure a wide spread of angles towards the phenomenon. Still a sampling describes the process of selecting a sample of elements from a target population to conduct a survey (Kvale & Brinkmann, 2014). All sampling is related to random errors. If all the people within the population of interest are not interviewed,

the selection will differ slightly from the actual population. The more people interviewed, the less this difference will be, but the problem can never be avoided altogether. For any specific single selection, it is not possible to know whether the random errors caused an underestimation or overestimation. Further, an interview is by nature exposed to the influence from the researcher, as it is impossible for the researcher to be completely objective. All interviews were semi- structured interviews, and the respondents were given the opportunity to verify the correctness of the interview transcripts used in the paper.

2.4 Researcher's pre-knowledge

There are numerous points where the researcher's own bias can affect the course of the research process. There is a growing recognition that it is impossible for a researcher to be completely objective and keep the research process unaffected by the researcher's own values. Bryman & Bell, (2011) list eight possible points of researcher value intrusion in the process: *choice of research area; formulation of research question; choice of method; formulation of research design and data collection techniques; implementation of data collection; analysis of data; interpretation of data; and conclusion*. Further, the researcher's prior knowledge, experience and attitude will highly affect the research process since this will influence how the researcher, not only see things, but also what the researcher sees. To minimize researcher bias, the research was conducted by adopting a thorough and systematic approach as described in previous section.

3 Frame of reference

The theoretical framework used in this thesis will begin by explaining the notions of the structural design and construction process and how this is interpreted in the research. Continuing with involved roles and finally a brief overview of integration as perceived in construction. Integration as such is perceived as very important in the transition towards a more effective and sustainable construction process. In short, integration is required to meet the increased complexity of the task of managing productivity, cost, resource efficiency, sustainability etc. Today, even the smallest projects that include only simple and single bridges are complex in their entirety when it comes to optimization based on an increased degree of resource efficiency, including both time, cost and materials.

3.1 The structural design and construction planning process

The (building and) construction industry is usually divided into different sectors or segments. It is usually categorised by sector, such as residential, commercial, institutional, or public works and infrastructure. Further, you may also classify by the involved professions or activities, such as construction, consulting, materials and equipment supplier or manufacturer, owners and operators, etc. While the construction process has evolved over the years and increased in complexity, also the separation of the design and construction roles has increased under the traditional form of construction procurement (e.g. Puddicombe, 1997). As a result the construction industry has by tradition been, and still is, exposed to fragmentation between its stages together with a relational short-term perspective (Anumba *et al.*, 2002).

Thus, the process of construction can be viewed as an arena for collaboration between numerous of suppliers all from early design stages up until completion of construction. The nature of construction requires interaction among several different parties or professions and progress is achieved by involved participants by continuous negotiations. Still this is a process not clearly owned by any part and these negotiations are predominantly done with each individual product at focus, not project success. The process itself looks more incidental, but none the less, this is the process which determine the key outcome (Oakland and Marosszeky, 2006).

Further, bridge construction and bridge categories involve a large number of different structures, ranging from small steel-and-soil composite bridges to mega structures spanning barriers never thought to be bridged. In the everyday light, the large mega structures usually get all the attention, but most bridges are relatively small and modest. For most bridges, still necessary to bridge smaller obstacles, they are just a small part of a much longer piece of road and need to be designed accordingly. Consequently, where to place the bridge, possible location for supports, available space for traffic etc. are limitations that naturally encapsulate bridge construction projects.

Construction is also a project-based industry and due to the already mentioned fragmentation, there are also exists several sources of waste and values loss. During construction, the obvious value is generated while producing construction works, whether it is in terms of new structures and buildings or by improving the already built environment (Anumba *et al.*, 2007). Still, many of the fundamental and basic decisions which are taken early in design, such as bridge type, design materials, detailing etc. highly affects the ability to fulfil both present and future requirements. Such requirements may very well include both functional requirements as more traditional such as safety, accessibility, environmental, aesthetics, cost efficiency, life span,

flexibility. Early stage decisions are naturally taken with a higher degree of uncertainty but may still have a large impact, both short term and long term, on project or even national economy, since decisions affects both durability and the need for future repair and maintenance (fib Bulletin 01, 1999). Consequently, these early stages constitute a large effect on the overall success of the project. Responsible members from different disciplines needs to establish a collaborative environment early on and find solutions acceptable to all disciplines.

There are several ways to define and divide the stages of a construction project. To explain the typical construction project, including design, construction, maintenance and demolition processes, it can generally be divided into three different stages; pre-construction, construction and post-construction. During those stages, numerous tasks and activities are performed to fulfil the objectives and output specified by the owner. The main objective of any construction project is to finalize and deliver construction works, so from a customer perspective, this distinction of different stages with construction as a central part is of course rational and logical in that sense, Figure 5.

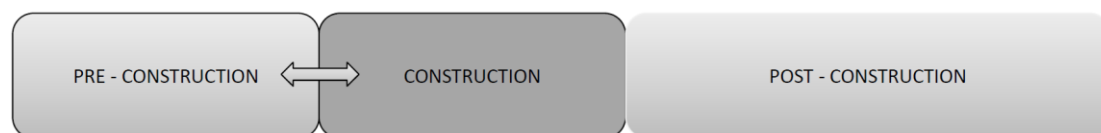


Figure 5: The construction project process can be divided into three main stages.

However, how the design task is undertaken during the pre-construction stages, and how this best can facilitate the activities in the construction stage is the main interest in this project.

Pre-construction stage

During the pre-construction stage, the purpose is to develop the client's needs into a final and appropriate design solution. At this stage it is important to identify and understand the customer's idea and needs since such an understanding creates the framework for establishing the design. This stage includes several different stages, or levels, of design and is usually divided into three phases, namely conceptual, preliminary and detailed design, e.g. (fib Bulletin 01, 1999; Mora *et al.*, 2006). Detailed design can further be divided into general design (or basic design) and final design (or execution design), although this division is traditionally not often used in Sweden (e.g. Harryson, 2008).

The process of structural engineering and design of new infrastructure is to its nature still an iterative and creative process based on both science and state-of-the-art knowledge. The earlier in the process you look, the more ambiguous it is. The structural design process usually includes several engineering disciplines and groups of people representing various fields of knowledge. The process is also to a large extent limited by the available experience and knowledge possessed by the project members involved such as owners, engineers, designers, and project leaders. Collaborative efforts and exchange of information are thus often a necessity to bring the project to a satisfactory conclusion within the scheduled parameters. Included in the responsibilities of a design team is to deliver a design which fulfils the client's need both in required time as well as without unjustified cost. The characteristics and the outcome of a good design includes sufficient durability, reliability, low cost, high accuracy, simplicity, low maintenance, and aesthetical appeal. Further requirements of contemporary design and

structural engineering also include life-cycle design, based on the ‘cradle to grave’ approach (Larsson, 2009; Owen *et al.*, 2010; Landolfo *et al.*, 2011; Muigai *et al.*, 2016).

Construction stage

When entering construction stage, all the necessary elements of a project that will enable its performance should be in place (Anumba *et al.*, 2007). Construction operations are highly diverse as they are performed under very different conditions, require many different types of resources, and also present a range of risks (Tatum, 2005). If the full benefits of coordination and communication have been addressed during the pre-construction stage, it is here the gain will be fully realised (Anumba *et al.*, 2007). Preferably, the only concern should be the construction works and production of the final structural solution since, at this stage, usually any changes in client’s requirements or interference with production/construction come at a high cost. Thus, discussions regarding productivity improvements are basically aimed towards this stage, see e.g. (Jergeas, 2009; Simonsson, 2011), and usually include benefits from, for example pre-fabrication, pre-assembly, off-site manufacturing etc.

Yet, studies have shown that too much time and effort are spent on the construction site trying to make the designs work in practice. For defects and rework related to design, those originating from missing co-ordination between disciplines are the largest category (Josephson and Hammarlund, 1999). Research indicates that, on average, 1/3 of the defect costs originates in pre-construction activities, i.e. can be referred to the design phase (Josephson & Saukkoriipi, 2005; Love & Sing, 2012). Engineering design as such, is consequently very important but also needs to be considered as part of a larger process. For example Olofsson, (2003), points to the risk that serious damage is largest during the construction stage based on the reason that this stage might have been neglected during the design. Consequently, if no other discipline or function completes these activities prior to construction, then construction workers will have to complete them (Tatum, 2005).

Still, safety during construction is a very high priority aspect for all construction firms and becomes a critical issue during e.g. lifts, assembling, and launching. The responsibility for customization during construction and the design of temporary structures is then often transferred to the contractor and it is therefore crucial that sufficient knowledge exist. This has evidently not always been the case. The knowledge about structural behaviour during temporary stages and the design of temporary structures and the belonging risks are something that is handled and considered as vital for any serious design-, engineering- or production process. While leaving key activities to the field therefore fails to realize potential project advantages from performing them earlier in the project and integrating them with other activities for the best project solutions. (Tatum, 2005)

Post-construction stage

This is the stage where traditional construction projects terminate and client taking ownership of the built structure. Even though the designing engineer/team are usually long since disconnected from the project, the effects of their choices during design will be present. During the service life of a bridge, several activities will take place which also are influenced by decisions during design, as well as activities during construction works. Some examples are inspection, accessibility, maintenance, repair, demolition, replacing, recycling. The effects of design during the service life will be related to structural strength, durability, operability as well as sustainability. Considering the long

service-life for bridges, a successful design will generate a structure with a well-balanced cost between structural performance, repair and maintenance, and operability.

3.2 The trinity of involved roles

In relation to housing, the constellation in a bridge construction project is usually quite simple in its composition. For this thesis the area being studied is the trinity of client, contractor, and the consultant. Of course, to complete a bridge construction project will involve more disciplines than that, but in most bridge construction projects these are the main key actors. Further, as this research are interested in the interface between the contractor and consultants, roles as construction engineer and structural engineer are used to emphasize the tasks they do.

The previously mentioned divided and sequential propulsion of a construction project also creates a separation of powers, which in turn establishes an arena where control of the project is a potential source of conflict. Normally the structural engineer is responsible for design issues, and accordingly, the contractor or construction engineer is responsible for all methods and materials used for construction works. Construction is awarded to a contractor who procures material, labour, and equipment and executes the contract requirements. This separation is an artefact that denies the intrinsic link between design and construction.(Puddicombe, 1997)

The specialisation into different disciplines is still a necessity in order to manage the complexity in most construction projects. Although, design and construction are, as mentioned, extensions of each other, and project participants perceive control of the overall project as being crucial to the achievement of a successful outcome (Puddicombe 1997). Still, there is a need for the trinity to start to function as the, since long, forgotten master builder (Forbes & Ahmed, 2011; Smits, 2013)(. There is a widespread understanding of the differences between the disciplines, but usually these differences are addressed as hindrances to collaboration. Instead, embracing them and understanding how to use them as complementary in contrast to diverging, seems as a fundamental start. To do so, each discipline also needs to learn to fully understand its own role and part in the construction process, at least with the basic understanding for closest upstream and downstream actors and activities (Emmitt, 2010). As further elaborated on later in the thesis, most work in construction is connected by interdependent relations, and it is rarely possible to isolate your own work.

In the following sections, a brief overview of the main three involved parties in the trinity and their main responsibilities as it is used in the thesis.

Consultant - Structural engineer

Structural engineering, as used in this thesis, is applying awareness with, knowledge of, and appreciation for architectural design and construction means and methods along with a deep knowledge of the behaviour and performance of structural systems to create compatible, safe, functional, economical, and reliable design alternatives; to help identify the optimum design and construction concepts and details; and to define the form of the engineered system that allows effective construction and maximizes the quality and value to the owner and to society (Luth, 2011).

Structural design engineering involves deciding and configure the structural system, as well as defining the structural members and their cross-sections, and choosing materials. Of course, all with the objective to realize the optimal combination of material and structural shape. However, it is important to bear in mind that structural

design mostly involves solving open-ended problems and there is no definite solution. Based on the interdependency described by Figure 6, show a clear interdependency between profession and that the choices of one both control and limit opportunity for the other.

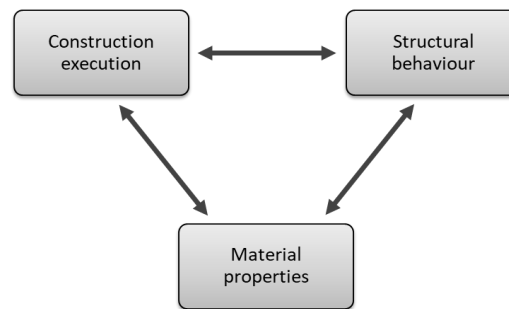


Figure 6: The design of a structure together with its characteristics and performance are strongly linked to the choice of materials that are used and their properties, as well as construction execution. Modified from (Löfgren, 2002)

Contractor - Construction engineer

The contractor is of course the role responsible for construction execution. This role includes many parts such as purchase, site logistics, project management, etc. In the interface with the structural engineer, the responsibility for the construction engineering includes a series of technical activities throughout the project to assist in meeting all types of project objectives. The activities include designing temporary works and processes for field operations, supplying temporary and permanent resources, and integrating team members and projects (Tatum, 2011).

Supported by integrated work processes, structural and construction engineering are responsible for collaboratively designing the permanent structure and the construction processes and temporary works required to build it (Tatum, 2011).

Bridge client

This chapter intends to describe the Swedish Transport administration in short and their part within bridge construction and in the bridge construction process.

In most countries, a public authority acts as the single most important client in the sector of infrastructure. In Sweden this is operated by the Swedish Transport Administration (STA). In addition to the STA, the Swedish bridge construction industry consists for the most part of approximately six to seven contractors and ten engineering consultancy firms active in bridge engineering design. Apart from very large projects, architects are very rarely used. Although these businesses have mutual differences, as a profession it is generally quite a homogenous industry. Over the years, the Swedish infrastructure market has been characterised by the traditional Design- Bid-Build (D-B-B) contract, but for bridge construction projects a modified version of Design-Build (DB) contracts has been in use for quite some time, leaving the contractor with larger, yet limited, control of detailed design. During recent years the STA has offensively introduced more D-B-B contracts, but more collaborative approaches are sparingly tested in large scale infrastructure projects.

3.3 Integration in design

Integrated design and construction as an expression may constitute a limitation in its own due to its vague statement and understanding. Still, design and construction integration have been discussed in the literature for a long time, together with the ambiguous questions of contractual relationships and how to benefit from collaborative approaches between companies during long term relationships e.g. (Bygballe *et al.*, 2010). These interdisciplinary methods (see e.g. Emmitt, 2010) in construction are best exemplified by multi-party contracting practices such as project alliancing, project partnering, integrated project delivery (IPD).

These contracting methods, usually referred to as ‘relational’, are based upon a relationship of trust between parties with fair division of responsibilities and benefits (Lahdenperä, 2012). The American Institute of Architects defined IPD as a “*method that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to reduce waste and optimize efficiency through all phases of design, fabrication and construction*” (The American Institute of Architects California Council, 2007). The relational aspect thus helps enrich inter-organizational relationships to deal with unforeseen events difficult to capture within the dictates of the contract definitions. Consequently, it encourages a flexible and speedy response to deal with the challenges usually associated with a risk event that has not been explicitly addressed in the contract.

However, this challenge is not completely understood and very little has been adopted within projects in the Swedish construction industry up to date. Contractual arrangements are only a subset of the transition towards a more efficient and sustainable construction process and can only establish the prerequisites for a project to be successful. The degree of success still lies in the hands of the project participants, i.e. the individuals involved in the daily work of engineering and construction activities. So, to reap success in a construction project, the project team should strive for an integrated project process, with a focus on the end-product, and formulate clear project goals and specify priorities regarding quality, cost, and time.

In this thesis, the meaning of an integrated design and construction process is an approach to undertake the work by a collaborative, integrated and interdisciplinary approach. Many of the concepts and methods proposed in literature are by nature multi/interdisciplinary and complex. Although several sources for the definition of integrated design exist, the basic is to implement all relevant and significant requirements into one single design process (fib Bulletin 71, 2013). Commonly defined characteristics of integrated design are a holistic mind-set and the goal of improving the performance of the resulting building structure by including long-term performance as a criterion from the earliest parts of the design process (fib Bulletin 71, 2013).

The complexity of the approach also involves a situation where the proposed changes might mean different things to the different participants within a project. Integration of design and construction often generates opportunities for the client to generate greater efficiency in construction, resulting in lower cost, reduced construction time, and/or improved quality. For the engineer, awareness of such opportunities enables an understanding for the methods and constraints of the actual construction required to execute the design. For the contractor, it is a combination of efforts required to

implement the design most efficiently and the opportunity to minimize the resource effort and cost.

The integration of design and construction as used here is not intended by merging different stages. Instead, the integration refers to the flow and use of information and how knowledge is used to transform the needs and requirements from the client and contractor into the final product. Still, the prevailing pre-construction stage consist of a fragmented approach between different design phases and different trades. It is during these phases which literature frequently suggests increased collaboration and integration to enhance the outcome of a construction project (Anumba, Baugh and Khalfan, 2002; Larsson, 2009; Owen *et al.*, 2010). To do so, this normally requires overlap of domains, for example that a contractor more actively take part during design development and in the conceptual discussions or even to compete with different bridge concepts or the structural engineer gets involved in upstream activities to support in the architectural design (Uihlein, 2015). However, the appropriate level of integration may vary from project to project and for some projects, the early or extended integration might be unnecessary and unproductive. Barriers and costs associated with integration needs to be evaluated since it may outweigh the benefits.

Many project-based industries have recognized that multi-function teams reduce the probability of costly changes and production difficulties. This is enabled by addressing design and production decisions earlier in the process (Crowley, 1998; Anumba *et al.*, 2002). Uihlein (2015) studied the integration between architects and engineers and what aspects were the underlying drivers regarding the structural integration. From the results, the time when structural engineers were introduced to the projects was considered a very important factor. The importance was found at several layers or organisational levels. If introduced in conceptual stages the structural engineers could not only be involved in the development of structural ideas in line with the aesthetics, the engineer can also attend to avoid structural inefficiencies. On the more individual level, the feeling of being valued as an asset to the end-product was significant to the engineers, clearly indicating the social part of the process. From an individual perspective, it is natural to desire to influence as far upstream as possible and to gain control and dictate your own conditions. By this, of course, the traditional domains between participants begin to overlap. This overlap offers opportunities for collaborative work and ultimately a shared understanding between all the stakeholders already in earlier stages of the project.

At this stage, an engineer can not only offer suggestions and develop structural ideas in keeping with the architectural concept, but the engineer can prevent structural inefficiencies from being added to the scheme. Additionally, this early inclusion signified to engineers that their input was valued as they were being given the opportunity to invest in the big ideas — architectural and structural—of the project. If knowledge from contractor or construction engineering (Tatum & Luth, 2012) is added and invested in — structural and construction — this investment is of course value added to the design process. This integrated and concurrent structural and construction engineering process is a way to achieve an efficient design process adapted to facilitate construction to be performed effectively.

Teams in the construction process

In modern construction management interest has increasingly shifted towards teams. In fact, the general view is that teams are expected to deliver better results than the average collection of individuals (Katzenbach & Smith, 1993; Wheelan, 2016). Several authors even assert that teamwork is not an option, it is a prerequisite for successful delivery of construction projects (Stewart & Barrick, 2000; Baiden, 2006; Salas *et al.*, 2017). Integrated design teams, as used in construction, serve to remove the traditional separation between design engineering and construction planning. Bringing together individuals and organisations with different knowledge and skills also creates a culture of efficient and effective collaboration to enhance the outcome of construction (Anumba *et al.*, 2002; Larsson, 2009; Owen *et al.*, 2010).

Examples of successful teams, for example in manufacturing, are teams sharing experience from multiple projects, and who have developed a shared culture and organisation of work and design processes. Project teams in construction on the other hand, usually work together only for the development of a single project and consequently rarely work together on more than one project (Anumba *et al.*, 2007; Senaratne & Hapuarachchi, 2009; Senaratne & Gunawardane, 2015). As a consequence of the prevailing short-term perspective in construction, there is always a significant risk that, if not well managed, design coalitions in construction will not perform well, or might even be dysfunctional (Sumner *et al.*, 1999; Forgues & Koskela, 2008).

In their research, Forgues and Koskela, (2008) found two opposing transition paths from traditional design practices towards new collaborative approaches; a development from a linear and sequential to an iterative design process; or a change in how projects are procured. Furthermore, when discussing integrated projects, it is normally the contract or the way of procurement that is given the primary focus (Kadefors, 2002, 2004; The American Institute of Architects California Council, 2007; Mosey, 2009). This limited focus is usually not enough and therefore results in a far too narrow interpretation for moving from fragmented to integrated design (Forgues & Koskela, 2009). Problems with project performance of integrated design teams are in general related to the context and not necessarily the process itself, i.e. they are not technical but socio-cognitive (Moore & Dainty, 1999; Baiden *et al.*, 2003; Forgues & Koskela, 2008).

Collaborative procurement approaches, such as Partnering (Kadefors, 2002; Bygballe *et al.*, 2010), Integrated Project Delivery (The American Institute of Architects California Council, 2007) and Early Contractor Involvement (Mosey, 2009) for example, function to stabilize and formalize the patterns between the client and its suppliers to improve the environment for an integrated design team performance. Yet, Forgues and Koskela, (2009) bring attention to the need for change also in relational patterns. The lack of socio-cognitive attention in design is supported by the results from Cross and Cross, (1995), who concluded that, especially in the engineering domain, the design process is normally treated as a technical process: a rationalized approach as a sequence of activities to solve a technical problem. Team work, however, is not only a clearly social process, the outcome of design is also limited to the cognitive skills and limitations of the individual designer/engineer. Cross and Cross, (1995), recommended treating the design process as an integration of a technical, a cognitive, and a social process.

Activities in construction are performed by individuals with different skills belonging to different companies in temporary organisations. These actors need to share

information and knowledge for optimum decisions. Management of these activities performed by individuals and groups of individuals within the organisation is coordinated to ensure a value flow, and therefore an organised flow in the work schedule. Creating both efficiency and effectiveness within the team in a construction project is consequently necessary and always needs to improve.

Process development

Since the construction industry started to adopt Lean philosophies, several methods have emerged to undertake and facilitate construction projects. Focusing on processes shifts the attention from individual products to the chain of activities that create them. Furthermore, a process focus instead promotes the question "how are the results produced" in favour of "who does what?".

Larsson *et al.*, (2014) present that two strategies that normally are undertaken to minimize the complexity of construction; standardization of products and standardization of processes. It is also stated that it has proven difficult to achieve standardization in both areas since the experiences and innovative ideas from contractors are not utilised in early stages of design. Some core elements to support standardization and increase the industrialization of infrastructure construction are identified in the article, and some barriers and its actors which have the power to eliminate them. Many of the core elements identified are related to long term actions, such as processes, rather than short term actions, such as projects. Here, integration between design and production is identified as one of the five largest core elements. Notably, and very interestingly, three out of the five largest perceived barriers can be eliminated by the client's role. Hence, lack of repetition in construction, prevailing procurement approaches, norms, and regulations.

Knowledge as such is both a complex and multifaceted phenomenon with a long history within the field of philosophy. Engaging in any discussion regarding what knowledge is or what is not lies far beyond the scope of this thesis. Instead, the discussion here is limited to focus on the dimensions of knowledge required to understand the complexity of knowledge transfer.

A fundamental prerequisite when introducing and managing industrial methods in the construction industry is to have systems to handle experience feedback. Adopting an approach for standardization and continuous improvements establishes the foundation for a learning organization (Lessing, 2006; Simonsson, 2011; Lidelöw *et al.*, 2015). In design firms, while being a knowledge enterprise, stored knowledge usually is available in reference documents from completed projects, or in the form of knowledge at the individual level. With inadequate management of information along with staff turnover there is a high risk of losing valuable knowledge if this is not handled properly. An often used citation is "we know more than we can tell" (Polanyi, 1983). By this Polanyi, (1983), indicates that when knowledge is stored on an individual level, an organization's level of knowledge may very well exceed what it explicitly can express. This problem clearly gives an indication that it is necessary to find a systematic way to carefully nurture the knowledge gained within a team or organization by creating a learning environment. Sumner *et al.*, (1999) states that "Integrating working and learning is not a desirable luxury – it is a fundamental requirement for businesses to remain competitive."

Simplicity in design and ease of construction is something valued by contractors and a challenge for the designing engineers. The possibility to influence the future properties

of a structure is at its largest during the different pre-construction stages. This is well known to the industry. The design and execution of a construction are closely attached and highly dependent to each other and consequently, the choice of construction method may very well dictate the rules of the design. Due to the sequential design process, a construction method often needs to be assumed in design without necessarily considering all its requirements (Fischer & Tatum, 1997). Even though there is an obvious need for construction knowledge in design work, there is a lack of a consistent and structured transmission of experience between the contractors and the designing engineers (Olofsson *et al.*, 2010).

4 Results

The results in this thesis are represented in four appended research papers. The brief summary presented in this chapter focuses on the main findings gained from each of the studies and thus leaving less room for how the results were obtained and the theoretical context in which they reside. The full descriptions can be found in the appended papers in the back of this thesis. The papers are appended in the same order as they emerged in the research project.

4.1 Paper A

Paper A is the result of a review of approaches developed as a response to the increasing demand for more efficient and competitive ways to design and constructing bridges. Given by the vast amount of existing literature, to make a significant change in the industry and especially when a transformative change is asked for, is perceived as difficult and cumbersome. Changes of such category requires time and continuity to sufficiently monitor and measure the effects of any implemented changes. A detailed review of literature identified that the reviewed concepts are very similar, not only in their expected outcomes, but also in its governing features. Although the concepts are developed from different perspective and stages, the review suggests that there is a variety of factors influencing the adoption of each concept that are previously not connected to implementation difficulties. In this paper, the authors address this identified gap by adding a holistic interpretation to the governing features in each approach.

Technical parameters	Non-technical parameters
<ul style="list-style-type: none">• Standardization of products and processes• Critical design variables• Systems thinking• Exploitation of ICT	<ul style="list-style-type: none">• Holistic view• Focus in customer value• Continuous improvement• Early integration• Appropriate members• Team skills• Sharing knowledge• Culture• Common goals

Figure 7: Main features that commonly influence the adoption to process oriented bridge construction.

The result of this detailed review identified a few main features that commonly influence the adoption to more process oriented and integrated approach in bridge construction, Figure 7. Besides the similarities between the main features which constitutes the different concepts, these main features can also be divided into (1) technical parameters: standardization of products and processes, critical design variables, systems thinking and exploitation of ICT; and (2) non-technical parameters: holistic view, focus on customer value, continuous improvement, early integration, appropriate members and team skills, sharing knowledge, culture and common goals. The number of governing non-technical parameters linking the features out-numbers the technical parameters. Still, how to accommodate these non-technical parameters in integration, and how this affects the integrated team have been overlooked. How to sufficiently undertake design and how to facilitate a team approach during pre-construction stages are relatively unexplored in Swedish literature and needs to be addressed further.

4.2 Paper B

Paper B elaborates on the results from paper A, that adopting an integrated design approach in construction and establishing integrated project teams (IPT) in the early stages intends to facilitate the configuration of an end-product with a structural design based on well-substantiated and reasoned decisions. Paper A clearly indicated that the expected effectiveness in design is commonly connected to what is referred to as highly functional teams (Baiden *et al.*, 2006; Salas *et al.*, 2017). However, how to best create and benefit from these teams is still not clear.

For example, there are several interfaces in the every-day project setting where experience feedback and knowledge transformation are possible to use, and there are opportunities to take important steps to create effectiveness over time. But the long term business relations within project teams, including experience feedback over time, are scarce today and any systematic experience feedback or knowledge transformation is seldom or never utilized, e.g. (Gadde & Dubois, 2010). So, despite all previous observations, the mechanisms of how integrated project teams are established within projects and how to influence performance are still areas that needs further clarification.

By adopting a multilevel approach, and including the individual, project, and organisational levels, the paper evaluates perceived project performance amongst Swedish bridge industry participants. The established framework, see Figure 8, aided to examine the collaboration between different disciplines during the development of construction documents for new bridges in Sweden. The result shows, that out of nine evaluated key areas, more immediate attention is crucial concerning *project culture*, *project competence*, and *organisational structure*.

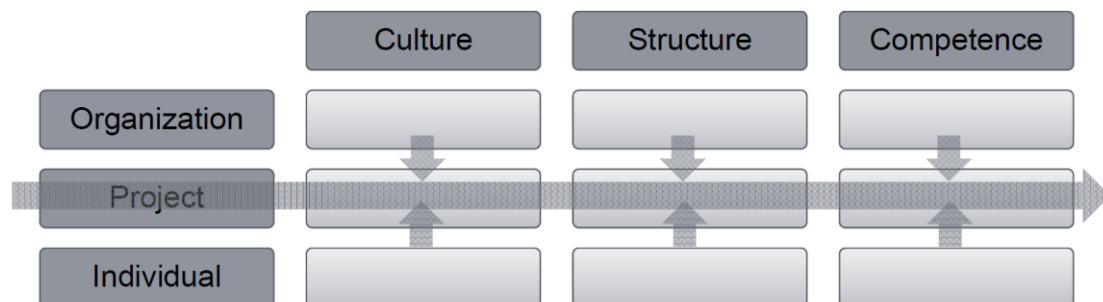


Figure 8: Survey evaluation matrix used in Paper B. The framework was established by cross-mapping organisational levels towards attributes concerning culture, structure, and competence.

Even though the greatest potential for improvement was found at the project team level, the individual contribution and the organisational support to the project team's performance cannot be overlooked or neglected. Reliable measurements are needed on all levels to sufficiently capture the true project performance and to fully benefit from the project team. The outcome and performance from the application of Integrated Project Team (IPT) in the Swedish construction industry are yet poorly evaluated. The lack of knowledge how to sufficiently collaborate in a project team setting, which is indicated by the score in *Project Culture*, are also supported by the results in previous research presented in Paper A.

4.3 Paper C

Paper C builds upon the results presented in paper B, by further investigating the indicators concerning *project culture*, *project competence*, and *organisational structure*. Although problems may arise connected to the intra-professional communication, this study focuses on the interface between the structural design engineer and the construction engineer, i.e. towards the inter-professional dialogue concerning the *what* and the *how*, (e.g. AIA, 2007).

The study for this research began with the goal to better understand the interprofessional dialogue and how experience and knowledge feedback is handled and understood amongst construction industry participants. The adopted interview methodology made possible to further understand the complexity of the interprofessional dialogue and the research interviews offered an important means for the researchers to deepen their understanding concerning structural and construction engineering integration. The findings are presented in form of observations presented in Figure 9.

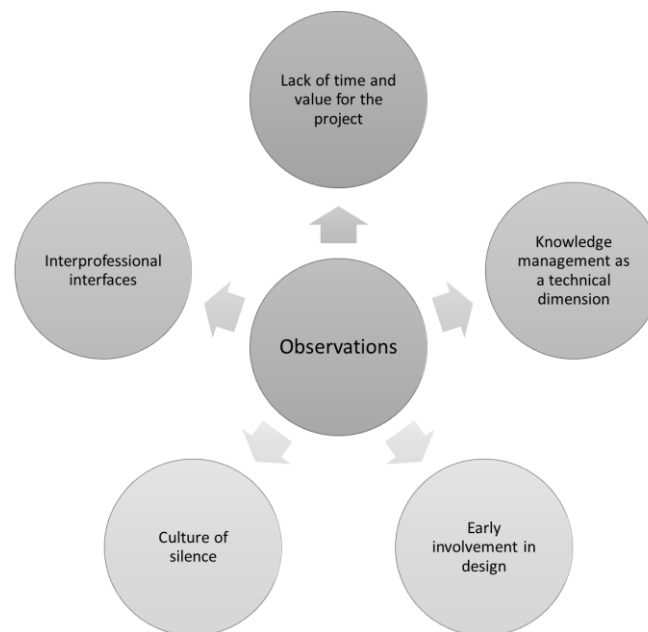


Figure 9: Interviews emerged in five observations; Lack of time and value for the project; Knowledge management as a technical dimension; Early involvement in design; Culture of silence and Interprofessional interfaces

Findings from this research supported the authors to conclude that there is a clear distinction between two situations where the interface between structural design and construction needs to be bridged. Unfortunately, at both these opportunities the structural engineer and contractor are normally separated which distinctly prevents the possibility for a constructive interprofessional dialogue.

Firstly, there is an interface during the development of construction documents, the actual input of knowledge to generate solutions (knowledge creation/knowledge transfer). During this stage, even when possible, there is no indication for any widespread effort for creating supporting activities, instead the projects team members are usually strictly bound to solve given tasks within their own professional domain. One important pillar in that development of aligned efforts is to understand the need of your project team-members. So, given that the environment of structural design (pre-construction design stage), contrary to the construction stage, is a qualitative, subjective

and in some sense related to a high degree of uncertainty, the appropriate methods and practices used in pre-construction stages are, thus, slightly different from those in construction. Consequently, there is evidently a need to establish a deeper understanding for the essentials and important task during each stage.

Secondly, the very action to learn from the results from the first (experience feedback/knowledge creation), the actual effort for evaluation and retrieval of experiences from previously performed projects. The interprofessional dialogue seem prevented by a two-way continence. Instead of engaging in dialogue, both parties are expected to understand the implications from their own actions. This becomes more apparent for small projects where there is less opportunities to repeat the same action or solution within the same project.

Supported by the above it is clear that both structural engineers and contractors establish a deeper understanding about each other and learn how to speak a common language to support the interprofessional dialogue and in the long run the performance of integrated project teams.

4.4 Paper D

Paper D explores the interprofessional dialogue between the structural engineer and contractor in a case study. The case for this study was chosen with the preconception to be a generally considered successful project, including the perspective of the client, contractor, as well as the structural design engineer. The construction project was a train-depot for regional trains, located in Stockholm, Sweden. The studied part of the project included an approximately 320 m long concrete tunnel and was executed in 2014, initially procured as a D-B-B-contract, i.e. complete construction documents were delivered by the client.

During construction planning, the contractor identified many time-consuming activities and other difficulties to improve. Together with the structural engineering company, the contractor had just completed the structural design of another project, including some long tunnels similar to this, and saw an opportunity to benefit from the experience of a previously successful collaboration and presented an alternative calculation to the client including a re-design. The date for construction start was fixed so there was time pressure to deliver the first construction documents. Within the original design there were several areas identified to improve and with the new design the intention was to optimize buildability and minimize risk during construction. The following areas were the most significant:

- construction method, including sequence, production rate etc.
- repeatability, simplicity, similarity in details
- minimizing shear reinforcement, and choice of bar type

To explore the dialogue the following question were asked (1) What characterizes the dialogue between the different disciplines; (2) What is the dialogue about; and (3) When in the process do questions arise? The main findings are presented in Figure 10

In most D-B-B construction projects, the possibility for any constructive dialogue between contractor and structural engineer is usually limited. For this specific case, finalized construction documents were provided to the contractor by the client due to a tight schedule. Although the construction documents were based on current codes and regulations, and assumed site conditions, the contractor saw great potential for improvements and wanted to re-design and remake the construction documents. While rethinking construction, the contractor established a clear picture of how they wanted to organize construction and could bring this input as new entry values to the new structural engineering company. In some way, there was a fairly completed "design intent" as an entry point for the contractor and the structural engineer dialogue.

The meeting documents distinguished that the interprofessional dialogue from the structural engineer to the contractor is much more difficult to identify than the opposite (Loop 1 and 3), see Figure 10. This dialogue may be embedded within the project delivery itself and the structural engineer's dialogue is conducted through the product or service that is provided, in this case the construction documents.

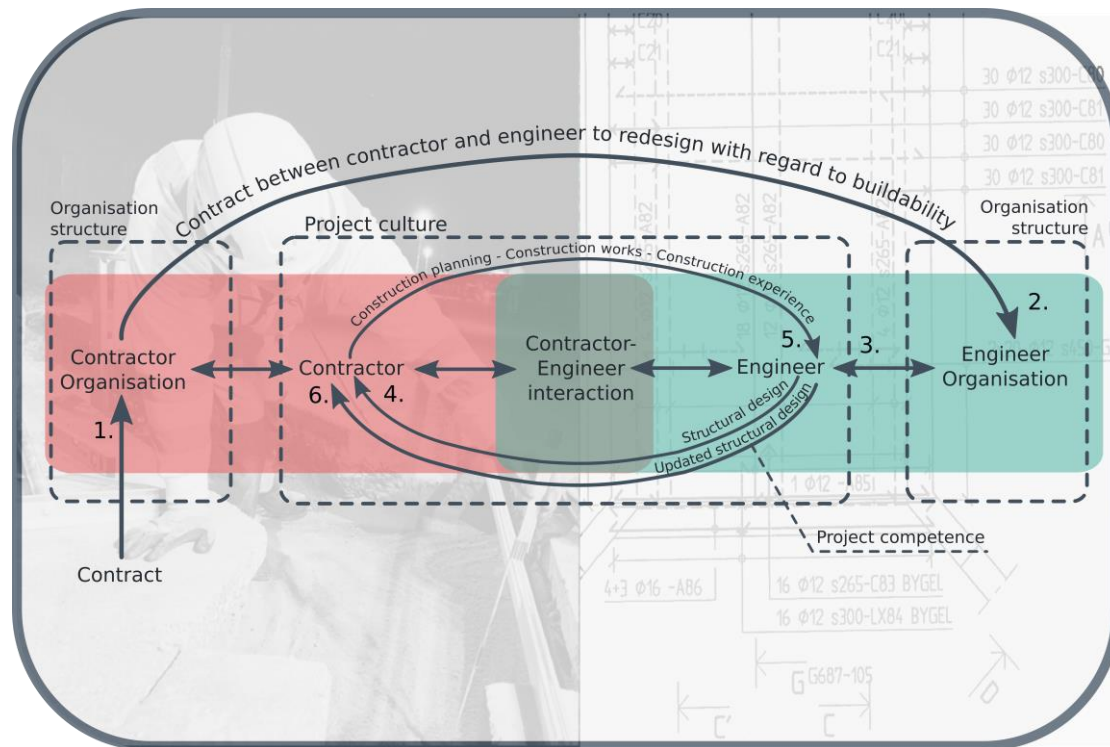


Figure 10: Illustrates the researchers' interpretation of the documents on how the interprofessional dialogues evolved during the project. clarifies some main topics that are affected during the dialogues and at what stage these topics appear. Further, it also describes the dialogues to appear in three loops originating from: (1) Initial structural design, (2) Construction -Planning/-Works/ and – Experience, (3) Updated structural design.

Further, meeting documents revealed a high presence from all actors. All parties had the individuals needed present to be decisive at the meeting and were thus organizationally ready, which simplifies the inter-disciplinary dialogue. It is normally difficult to receive early feedback on construction documents due to staff shifting between design and construction personnel. Such shifting is a problem since late error detection or changes leads to further time-rushed revisions or re-work that further increases the risk of errors. When the structural engineer needs input concerning reinforcement layout and intended construction sequencing, these issues have normally not yet come to light for the contractor. Further, when the contractor starts to think about construction procedures, the structural engineer has moved on to other projects.

The project was initially given very limited work-site area , so discussions about the possibility of utilizing the finished constructions became a clear issue. Questions such as: When and in what order can finished constructions be backfilled to make construction procedure more efficient? How is the access to and within the construction site and availability of cranes during staging? Can cranes be placed on top of finished construction works instead of alongside? The fact that these questions about construction procedures remain, highlights these issues as largely unpredictable. Yet, the project team demonstrated a strive to constantly improve and streamline construction procedures when solving them.

An environment for collaborative efforts needs to be established and supported by the client. Here, allowing for a re-evaluation of the structural design and construction

planning created that environment despite the short available time and the established interprofessional dialogue enabled a sound project team development.

Further, to support the interprofessional dialogue requires some form of vehicle, it is important of have something to discuss around, otherwise the dialogue tend to fail . Allowing the contractor to establish a "design intent" created that vehicle to carry the dialogue.

4.5 Discussion and conclusion

This section aims to interpret and describe the significance of the findings and highlight observations and new insights rendered by this research by addressing the two research questions in order.

The first research question aims to define integration as related to bridge construction process and what are the key features for integration. The second research question aims to define the interprofessional dialogue in the bridge construction process and how this support/hinders knowledge and experience transfer in the interprofessional interface.

RQ1: What is integration, and what are its key features in relation to the bridge construction process?

To succeed in realizing effectiveness with construction efforts can only be made possible by close cooperation between all project participants, i.e. client , consultant(s), contractor(s), and suppliers (Jergeas & Van der Put, 2001). To improve the relation between the structural design and construction it is necessary to identify the common interfaces between the disciplines, as elaborated on in Paper A. With the complexity in construction today, it is important to consider the construction process as different stages with various outcomes as the primary objective, where structural design is one such stage. For this to happen, recognizing that each of involved participants, individually, might lack some pieces to puzzle, but that collectively, they can gather their knowledge and resources to achieve success for all of the participants (Jergeas & Van der Put, 2001). If integration is seen in this perspective the following key features crystallizes:

- skills to collaborate and communicate;
- interdependency between the parties;
- importance for the structural engineer to receive feedback from, and to have a dialogue with, the contractors;
- teams to be provided with the right people.

As presented in Paper A, the common intent with the integration and adopting a team approach is to overcome a linear and fragmented design approach. Construction projects are normally planned and executed in teams or groups, in one way or the other, and the outcome of a construction project is therefore in almost all cases dependent on individual skills to collaborate and communicate. The most common factors to the shortcomings that appear during construction can also be related to design errors. According to Claeson-Jonsson, (2013) the top three factors are (1) lack of communication between the client and the design team; (2) lack of understanding the production needs; and that (3) construction documents are not ready when production begins. Based on established communication in and between teams, such risks and uncertainties can commonly be reduced. As shown in Paper B, communication is a key feature for both project culture and team performance, maybe especially in construction due to its dependence on different professions. Communication, and more specifically,

knowledge transfer within and between disciplines was identified in Paper B, as a clear deficiency today.

Still, it would be overly simplistic to only proclaim that better communication will solve all the problems in construction. Communication in itself will not automatically lead to a better team performance. There is also a need to understand what to communicate about, to establish effective communication. To overcome such inefficiencies, the structural engineer or the structural design teams need to generate an understanding for site activities and core elements in construction. Further, the contractor also needs to create a deeper understanding about upstream activities, and to understand the structural design process, which is also highlighted as an important point by several contractors interviewed in Paper C. It is required for the different professions to overlap domains, and to be more active during adjacent stages than normal in order to better address, for example buildability considerations. These buildability considerations are not only subjected to uncertainty and risk during tendering stage for the contractor, e.g. (Olofsson *et al.*, 2010), they also generate interdependency between the parties involved. For contractors to operate construction activities both efficiently and competitively, they are directly dependent on the chosen design concept, the detailing, as well as the choice of materials, rendering another key feature (Löfgren, 2002). As previously mentioned, to understand this interdependency is important for both structural engineers as well as contractor since it effects both upstream and downstream activities. However, buildability considerations are normally based only on the structural engineer's knowledge or experience from previous construction projects and without the input from any appointed contractor. This lack of input is usually related to traditional procurement strategies where the contractor is procured first after fully realized construction documents. But as highlighted by interviewees in Paper C, involved organizations usually do not have the "right" people involved at the "right" time and the opportunity for improvements may pass. Still, when succeeding with the right staffing, as shown by the case study in Paper D, there is still possible to alter the outcome even within D-B-B contracts if only there is enough goodwill from the involved parties. There is also a clear trend that construction projects continue to increase in both size and complexity, which makes it more and more difficult for designers to be fully aware of all the implications from their designs. This complexity underlines a third key feature: the importance for the structural engineer to receive feedback from, and to have a dialogue with, the contractors who are experienced in construction engineering and meet the problems daily.

As several publications stresses (e.g. Hon, 1988; Lessing, 2006; Anumba *et al.*, 2007), most concepts contain both technical and non-technical parameters, often also referred to as hard and soft parameters or systems. Blockley & Godfrey, (2017) further claims that such soft systems even enclose hard systems, meaning that the hard system is dependent on the soft in order for the overall success. As presented in Paper A, when unpacking the different approaches, they are found to be made out of the same core elements, which are mainly related to soft parameters, such as *a holistic view, focus on customer value, continuous improvement, early integration, appropriate members and team skills, sharing knowledge, culture, and common goals*. Consequently, based on individuals' intention, the outcome of our projects is in the hands of project team members.

That perspective further adds weight to "*Project success relies upon the right people having the right information at the right time*" (Anumba *et al.*, 2007, p. 106). This statement origins from a view in favour for the integrated and collaborative

environment which concurrent engineering proposes. While a bit simplistic, this statement does not lack reason. Still “*the challenge is to ensure that the right information gets to the appropriate person at the right time*” (Baiden & Price, 2011, p. 130). So as emphasized in Paper C (key feature four), it is critical for teams to be provided with the right people in order to be successful, also stressed by (Radtke and Jeffrey, 1993; Paris, Salas and Cannon-Bowers, 2000; Forbes & Ahmed, 2011). Baiden, (2006) underlines that the right people are a composition of personnel from owner, design-engineering and contractor organizations. These key members are recommended to be hand-picked and involved early in the projects as well as consistent through the different project stages. However, the right people may vary over time since the tasks to be solved are of varying nature and what available individuals’ organizations have contains a great deal of flexibility (Emmitt, 2010).

Still findings from Paper B suggests that multidisciplinary constellations in construction are rarely viewed or evaluated in terms of integrated teams. In most projects, though, the work is done in teams or groups, in one way or the other. To establish teams requires investment in time, and all tasks or problems do not require fully developed teams to solve them. It is therefore important to utilize team-work approaches to the degree that it is necessary. Based on established communication in and between teams, both risks and uncertainties are commonly reduced. Still, the client holds the main beneficial role of enhanced project performance and should establish the required and favourable environment for integrated teams to operate in.

RQ2: What defines the interprofessional dialogue in the bridge construction process and how can it support/hinders the introduction of construction knowledge during early design?

As stated in the previous section and demonstrated in Papers A and B, structural design and construction execution are clearly interdependent, and construction projects are becoming more and more complex. The complexity is growing in terms of size, where to build, as well as the requirements for sustainable development. That challenge may be addressed by further focusing on the integration and interdependency of construction professions.

As mentioned in the beginning of this section, there is no point only arguing for better communication without establishing what to communicate about. Even though a project contains more than the constructive dialogue, we still need to address what the dialogue should contain. Both in Paper C and D we follow the interprofessional dialogue between structural engineer and contractor concerning buildability issues. A common expression from contractors is that solid knowledge concerning construction activities is something that the structural engineer usually lacks and needs to acquire more. This is on a general level probably true, but the interviews in Paper C revealed a lacking understanding how this knowledge should be created or gained. Who is supposed to learn who? Fully understanding the complexity in construction and its related construction activities, however, is not exclusively linked to the structural engineer. Results from both Paper B and C show that there exist difficulties even with intra-dialogue, i.e. difficulties to learn or transfer understanding even within your own organization. This is true for all involved professions, since there are no specific indications that participants handle experiences in any structured way.

The interviews in Paper C revealed a clear hinder to knowledge transfer: an embedded “culture of silence” which strongly contributes to breaking the learning cycle in the construction process. This break or interference disables the opportunity to learn from

the experiences gained by the individual (Senge, 2006). During the construction stage, it is usually too late for any major alterations and for any detected errors or possible adjustments, corrective measures are instead taken to solve the issue here and now and without consideration or reflection if this could have been done any other way. From the engineer's perspective, stated in the interviews in Paper C, such "feedback loops" only appears when things have gone wrong enough.

In order to support the introduction of construction knowledge during early design it is important to engage in any opportunity to create long term learning. Especially for small projects, typically single short to medium span bridges, in contrast to large projects where you can benefit from the natural repeatability which creates the manoeuvring space to question used solutions and thinking patterns within the project, which could be seen as a result from the case study presented in Paper D. A clear benefit from reusing and sharing previous project experiences is that it creates an opportunity to align a specific task to be performed in a similar and repetitive way. The interprofessional dialogue that can be followed in Paper D, show a targeted work to minimize the variation in how, both structural engineers and contractors, perform a specific design and construction processes, and how this also is key to ensuring that the total product quality meets all customer requirements. Yet, by reuse there is always a significant risk to become prisoners of our own experience, i.e. we perform the next project in the same way as the previous one without really questioning or reflecting over the actual outcome of the same.

Adopting a stronger focus on the social perspective of learning, also requires an increased focus on, and importance assigned to, human interaction and collaboration. Knowledge needs to be treated as something people do, and stress the importance of the relationship between knowledge and action (Neve, 2015). Further Neve, (2015:13) states that *"If we are to learn from knowledgeable people, we need to search not only for their more abstract knowledge but also for their practical knowledge."* This addresses the need to continue to invest in the interprofessional dialogue in construction projects. It is during this dialogue the tacit, in contrast to the explicit, knowledge is in focus.

The findings in Paper D express that if the project culture and competence is present a knowledge and experience transfer is fostered and supported. So, how is this situation created? What in the project set-up renders an ideal culture and competence in a project? Looking back on the key-features it is suggested to render in the conclusion that it depends on the right people and their skill to communicate and interchange experience.

Evaluation of research approach

A large part of the conducted research relies on the foundation created in Paper A and Paper B. Even though we have only combined already validated research, both from team/group theory, as well as organization/management theory, there is always weaknesses which can relate to both our own evaluation of the results and our preconceptions. Not to forget the possible weakness in the already established research. Although, there several models existing in research similar to the one used here, e.g. (Ginnett, 2005), which gives the research more credibility.

The research also heavily relies on the results from evaluation in Paper B. Besides the peer-review process before publication, no other proper verification or test where conducted for the framework. The framework could have undergone a conceptual test in order to strengthen it, but the research group made a deliberate choice to focus on the results from the evaluation in this case.

Interactions of individuals subjected to psychological, social and contextual influences make the subject difficult to research in live business settings (Emmitt, 2010). Most of the studies in this thesis deal with gathering the perceptions of how participants perceive, understand or think under particular situations. Even though, for example Emmitt, (2010) highlight that this can be useful insights, he also give notice that the *perceptions of how people think they behave and how they actually behave can be quite different*.

4.6 Concluding remarks

There is a need to establish a deeper understanding that many possible choices, for example for a structural engineer, lies in the hand of someone else, such as a contractor or a client. There is a clear interdependency between professions in the construction process. Thus, it is important to see that these actions create a chain of dependencies between professions and that this requires a continuous dialogue to find the most suitable solution for each situation. The progression of sustainability as a driving force in society, see for example (fib Bulletin 71, 2013), states that the overall loser is on a totally different level when compared to when economy is the governing parameter. Economy as a driver instead tends to only praise the winner.

From that perspective it important to develop a better understanding for other disciplines and their challenges. Further it is important that we learn how to operate in the other profession's domain. Including the contractor earlier in the projects consequently means that the contractor needs to gain or increase knowledge of the design stage and project planning, which many contractors highlight as a shortcoming, and find ways to reduce risks from participating in constructive interprofessional dialogues. This has been highlighted many times in previous research, but most aspects need to be addressed earlier and then the contractor also needs to learn how to plan production procedures in collaboration with the structural designer. This may require engaging competent and decision-making individuals during much earlier sages where they are not used to working. It is important to make buildability a team task with shared responsibility.

5 Future work

Applying technology can clearly support the social processes by managing and establishing more sound and reliable support for decisions. All forms of planning include working with preliminary results. It is not possible to do a complete analysis of a design until fully finished and all parameters involved are decided. In design, there is a search for something that is optimal, design includes optimizing constructions. There is a risk that it is just this action that makes the industry to believe that it is so unique. Something can only be optimal within certain, very clearly stated circumstances, and to find that optimum is cumbersome and here technology can aid. To use approaches such as Set based design (e.g. Mathern, 2019) within structural engineering is something relatively new. Still, the use of parametric computation needs to be valued against computational cost, and the result from the parametric computation needs to be clearly visualised and honestly evaluated. The risk in trying to optimize may be losing in the other end. Optimization is always done based upon specific pre-conditions which in construction can be unique. Making something unique of course narrows the opportunity to repetition. It might be important to apply optimization from a holistic point of view, for example keeping the same dimensions on a beam intersection despite varying length and instead using varying amount of reinforcement, i.e. optimizing only the reinforcement. Still, it is important to treat the design process as a combination both a social and technical process.

Based on the aim and purpose of the presented research and previous conclusion, the following point summarises the suggested future work

- Continue to study and investigate the performance stage to further strengthen the activities performed within the projects.
- Create further understanding of roles and responsibilities within the interdisciplinary project setting as enforcing sustainability and buildability issues.
- Further strengthening the need for a greater upstream-downstream understanding amongst construction industry participants. We need to minimize risk to dare participate in stages outside our own domain.
- Create further understanding of how a technical environment can support the project team decisions and aid in prioritizing challenges to avoid cost being the only considered factor.

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